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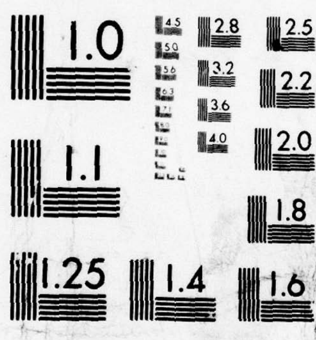

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The Sudden Commencement Solar Proton Flux Enhancement of 31 October 1972

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Interim Report

31 August 1979

Prepared for

SPACE AND MISSILE SYSTEMS ORGANIZATION
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This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Gerhard E. Aichinger

Gerhard E. Aichinger
Project Officer

FOR THE COMMANDER

Frank J. Bane

Frank J. Bane, Chief
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The sudden commencement (sc) solar proton enhancement of 31 October 1972 is examined in detail. The flux of 5-21 MeV protons observed by ATS-1 increased by a factor of 25 as a result of the sudden commencement. Drift echoes (indicating trapped particles) were seen clearly following the sc with a period of the order of 70 seconds as expected for protons with energies just above 5 MeV. Decay times ranging from 17 to 56 minutes were seen during the decay. The decay time changed as the magnetosphere reacted to varying solar wind conditions which were indicated by ground-based magnetometer

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records. It is also shown that plasma intrusions into the outer magnetosphere from the solar wind, as discussed by Lemaire and colleagues, can serve as strong scattering centers, providing access for and greatly reducing the otherwise expected trapping lifetimes of sc-enhance solar protons.

PREFACE

The authors are indebted to Drs. Gregor Morfill and Manfred Scholer for providing the trajectory code, Dr. J. Lemaire for comments about the penetration of plasma irregularities into the magnetosphere, Dr. M. Schulz for discussions about the dynamics of magnetospheric particles, Gwen Boyd and Lynn Friesen for computational assistance, and C. R. Hornback of NOAA for supplying the magnetic tape containing the Aerospace Corporation ATS-1 data.

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INTRODUCTION

Data acquired from synchronous altitude satellites have shown that protons with an energy of several MeV are present at $L \simeq 6.6$ only during solar proton events (Lanzerotti, 1968, 1970; Paulikas and Blake, 1970; Blake et al., 1974). It was shown also by Paulikas and Blake (1970) that this transient solar proton population can be substantially energized by the magnetospheric compressions which are observed on the ground as sudden commencements (sc's). Lanzerotti et al. (1971) found drift-periodic echoes in the energized proton fluxes observed following a sudden commencement. Recently Kremser et al. (1977) have reported observations of enhancements in energetic proton precipitation into the atmosphere during solar proton events associated with sudden commencements. These workers did not observe the solar protons directly,but measured with balloon-borne·instrumentation the gamma ray flux resulting from the nuclear interactions of the protons with the upper atmosphere.

The sudden commencement enhancements of the solar proton intensities reported to date (Paulikas and Blake, 1970; Lanzerotti et al., 1971; Blake et al., 1974) have differed substantially from one another in the amplitude and energy dependence of the flux increase, and the e-folding decay time of the flux enhancement. Such variations would be expected considering the variability in the incoming solar plasma and the associated energetic particles, and the prior state of the magnetosphere.

In this report we describe the most spectacular sc enhancement we have observed in several years of data obtained by ATS-1 and ATS-6. Our earlier sudden commencement observations of protons ($E > 5$MeV) showed (Table 2 in Paulikas and Blake, 1970) enhancements of a factor of 6 or less with e-folding decay times of 5 to 24 minutes and one example of a large enhancement, ~30, with a rapid decay time of 9 minutes. The sc enhancement reported here showed an intensity increase of a factor of 25, with an e-folding delay time varying from 17 to 56 minutes during the decay. Drift echoes were seen for many minutes. Changes in the configuration of the magnetosphere can be inferred from the decay phase of the proton fluxes; these changes were coincident with ground level observations of magnetic field changes. We also discuss the possibility that the marked variability in the decay time of the sc enhanced proton fluxes may result from the presence of plasma intrusions into the outer magnetosphere, originating in the solar wind (Lemaire and Roth, 1978), which serve as scattering centers for the solar protons.

SATELLITE AND INSTRUMENTATION

The solar proton data presented in this paper were obtained with the Aerospace Corporation experiment aboard the ATS-1 satellite. This satellite, in a geostationary orbit, is located on the geographic equator at 150°W longitude and thus is also on the geomagnetic equator.

The data were obtained from a pair of omnidirectional sensors with a 2π field-of-view directed normal to the satellite spin axis. The spin axis of ATS-1 is normal to the equatorial plane, and thus the proton sensors scan in the equatorial plane. A detailed discussion of the omnidirectional sensor design of the type flown on ATS-1 has been given by Paulikas et al. (1975, 1967) and Freden and Paulikas (1964).

Protons were measured in the energy intervals of 5-21 MeV and 21-70 MeV; these channels had no electron response. The accumulated proton counts were transmitted every 5.12 seconds. The conversion from counts per 5.12 seconds to omnidirectional flux (cm^{-2}-sec^{-1}) is made by multiplying the 5-21 MeV channel rate (counts per 5.12 sec) by 37, and the 21-70 MeV channel rate (counts per 5.12 sec) by 3.9.

RESULTS

The countrates (~ 1 min. averages) in the 5-21 MeV and 21-70 MeV channels are plotted as a function of time in Figure 1 for the time period between ≈16:37 UT and ≈18:05 UT on 31 October, 1972. Also plotted on the same timescale is the horizontal component of magnetic field measured by the Davao observatory (-4.00° Mag. Lat., 195.0° East Mag. Long.). Other magnetic data were examined; in particular the Tangerang (-17.62° Mag. Lat., 175.0° East Mag. Long.) observations were very similar to the Davao data. The local time of these two magnetic observatories and ATS-1 at 16:54 UT is shown schematically in Figure 2; note that the two magnetic observatories were near local noon.

A sudden commencement (sc) occurred at ≈16:54 UT simultaneously with the dramatic increase in the ATS-1 proton countrate in the 5-21 MeV channel. At the time of the sc, the interplanetary fluxes of solar protons with energies above 5 MeV started to decline after having been roughly constant in intensity for several hours (T. A. Fritz, private communication, 1976) and, within an hour, the interplanetary fluxes decreased by a factor of ~3. Thus the large proton enhancement observed by ATS-1 was of magnetospheric origin, similar to those observed earlier (Paulikas and Blake, 1970; Lanzerotti et al., 1971; Blake et al., 1974).

Figure 1 shows that, at the time of the sc, the 5-21 MeV channel countrate increased by a factor ≈25, whereas the 21-70 MeV channel increased by only a factor ~2, and the latter increase decayed away in a couple of minutes. Thus, as observed previously (Paulikas and Blake, 1970), the effect of this sc was to substantially steepen the energy spectrum as well as to increase the proton fluxes. Clearly the bulk of the

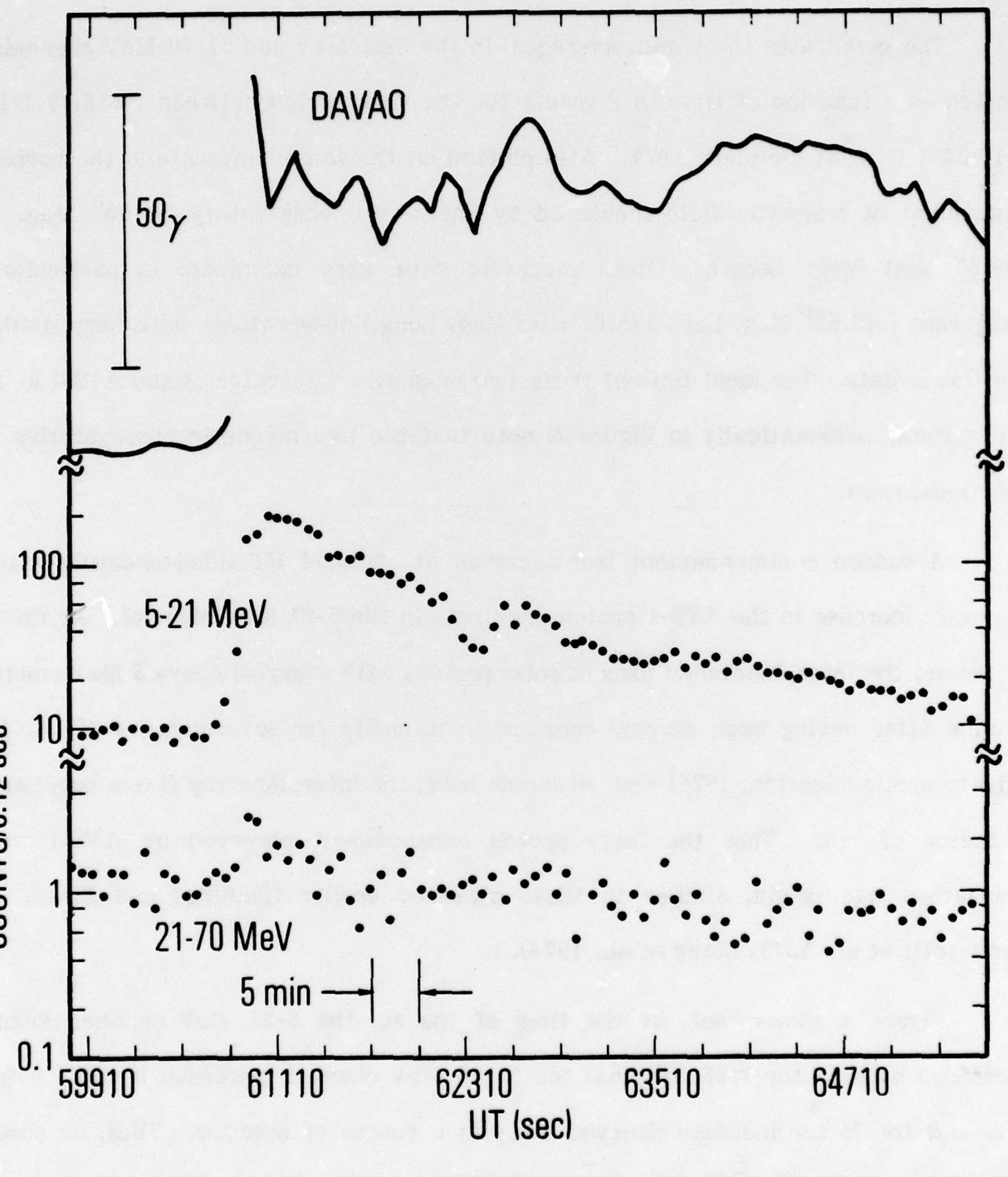


Figure 1. **The 1-Minute Averages of the Countrates in the 5-21 MeV and 21-70 MeV Channels and the Horizontal Component of the Magnetic Field as Measured by the Davao Observatory (-4.00 deg Mag. Lat., 195.0 deg Mag. Long.) are Plotted as a Function of Time for the Time Period Between ~16:37 UT and 18:05 UT on 31 October, 1972. The Points are Averages of 12 Data Frames or 81.44 Seconds.**

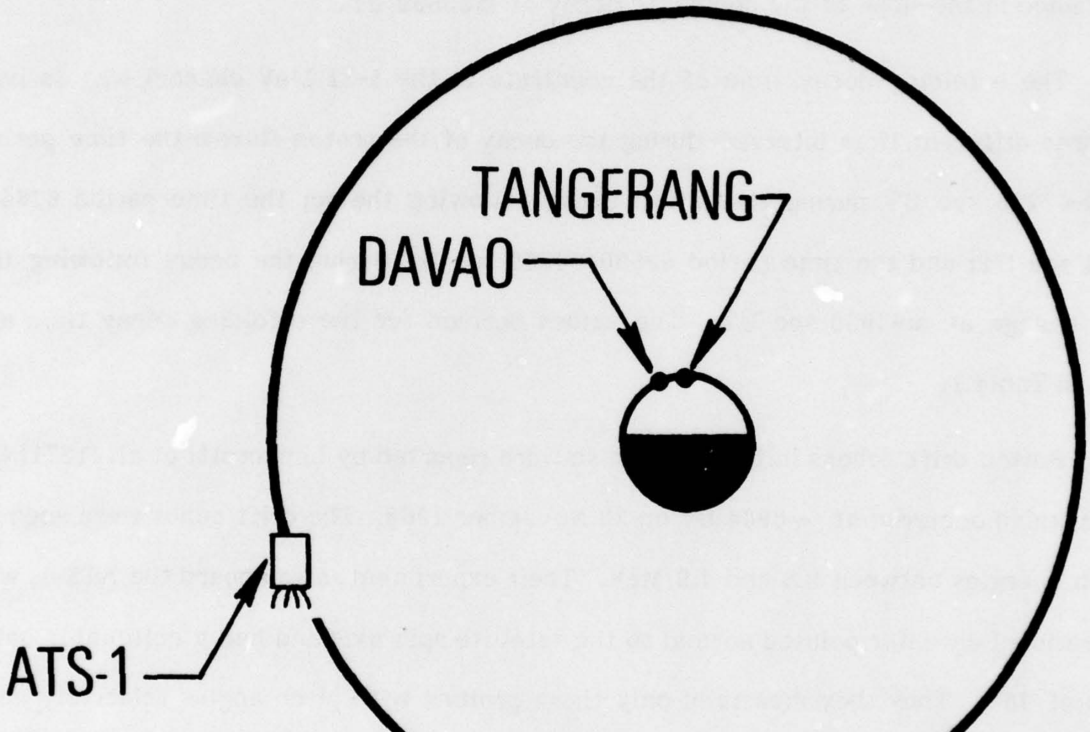


Figure 2. Location of Observation Sites at 16:52 UT on 31 October 1972

counts in the 5-21 MeV channel resulted from acceleration of protons to energies just above the threshold of the 5-21 MeV channel.

A comparison of the temporal evolution of the 5-21 MeV channel countrate with that of the Davao magnetometer record shows that subsequent (to the sc) changes in the configuration of the magnetosphere continued to affect the proton countrate in the 5-21 MeV channel. Obvious correlations between the magnetometer record and proton countrate can be seen at the time of the proton increase at $\approx$62490 UT, and the time of the change in the slope of the countrate decay at $\approx$63630 UT.

The e-folding decay time of the countrate in the 5-21 MeV channel was derived for three different time intervals during the decay of the proton fluxes: the time period 61440-62220 sec UT during the initial decay following the sc; the time period 62640-63300 sec UT; and the time period 63600-64560 sec UT during the decay following the slope change at $\approx$63630 sec UT. The values derived for the e-folding decay time are given in Table 1.

Proton drift echoes initiated by an sc were reported by Lanzerotti et al. (1971) for the sc which occurred at ~0904 UT on 20 November 1968. The drift echos were seen at proton energies between 0.6 and 4.9 MeV. Their experiment, also aboard the ATS-1, was a directional detector pointed normal to the satellite spin axis and had a collimator half-angle of 20°. Thus they measured only those protons with pitch angles relatively near 90°, in contrast to the Aerospace experiment which accepted protons with all pitch-angles. Drift echoes were not seen in the 5-21 MeV channel of the Aerospace experiment at that time or in other earlier ATS-1 observations such as those reported in Paulikas and Blake (1970).

However, following the sc flux enhancement reported here, drift echoes were seen in the 5-21 channel of the Aerospace experiment. In Figure 3 the countrate of the 5-21

MeV channel is plotted for the time interval between 16:48 UT and 18:12 UT with the highest time resolution available (number of counts per 5.12 sec); the modulation of the proton countrates can be seen in the data. In order to more accurately determine the period of the drift echoes, the power spectrum of the time series of proton countrates was estimated directly using the Hanning lag window and by using the maximum entropy method (Koopmans, 1974; Ulrich and Bishop, 1975; Thomson et al., 1976). The three time intervals specifically examined and the associated drift echo periods are given in Table 2.

TABLE 1

OBSERVED e-FOLD DECAY TIME

Time Interval (sec UT)	e-Folding Decay Period (min.)
61440 - 62220	17.1
62640 - 63300	13.8
63600 - 64560	56.4

TABLE 2

OBSERVED DRIFT ECHO PERIOD

Time Interval (UT)	Drift Echo Period (sec)
16:56 - 17:03	67
17:04 - 17:17	70
17:24 - 17:35	71

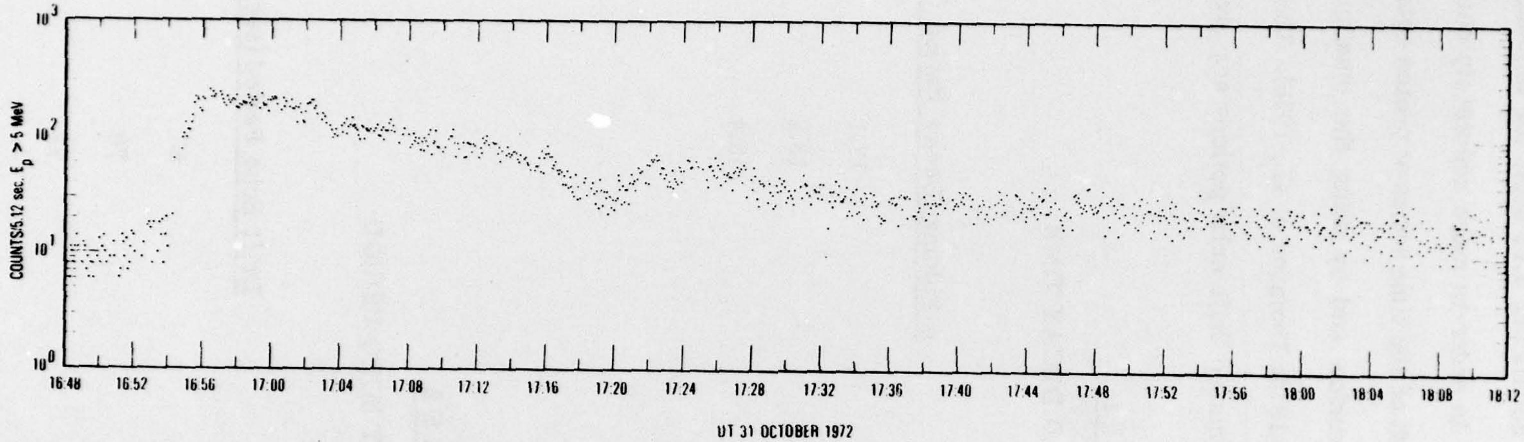


Figure 3. The Countrate in the 5-21 MeV Channel is Plotted for the Time Period Between 16:48 UT and 18:12 UT Using the Highest Available Time Resolution (Counts/5.12 Seconds). The Drift Echoes Can be Seen in the Countrates Following the Onset of the sc Enhancement.

DISCUSSION

It is of interest to compare the observed values of the proton drift period with theoretical estimates. In their monograph, Schulz and Lanzerotti (1974) discuss sc proton enhancements and give an expression for the azimuthal drift frequency Ω_3 (their eqn. 4.09) which, for L = 6.6, may be written as follows:

$$2\pi/\Omega_3 = \left[0.542\,\gamma/\,(\gamma^2 - 1)\right]\left[1 + 0.806\,(6.6/b)^3\right]^2 \qquad (1)$$

where b is the equatorial stand-off distance from the point dipole to the magnetopause in the noon meridian.

Equation 1 is for the case of equatorially mirroring particles. The nominal value for b is 10 R_e. As has been pointed out by Lanzerotti et al. (1971), if b is significantly smaller than ~9 R_e, the protons will be unable to complete a complete (2π) longitudinal drift but will exit the compressed magnetopause. The calculated energy dependence of the drift period, using equation 1, is shown in Figure 4 for b = 9 R_e and b = 10 R_e. The observations (Table 2) are plotted also.

It can be seen from Figure 4 that the observed drift echo periods correspond to the values calculated for protons with an energy of 6-7 MeV. In a dipole field protons mirroring off the equator drift more slowly (cf. Schulz and Lanzerotti, 1974) and somewhat more energetic protons (with equatorial pitch angles $<90^o$) would be required to give the observed ~70 sec drift period. In a compressed magnetosphere the protons with small equatorial pitch angles need not drift more slowly.

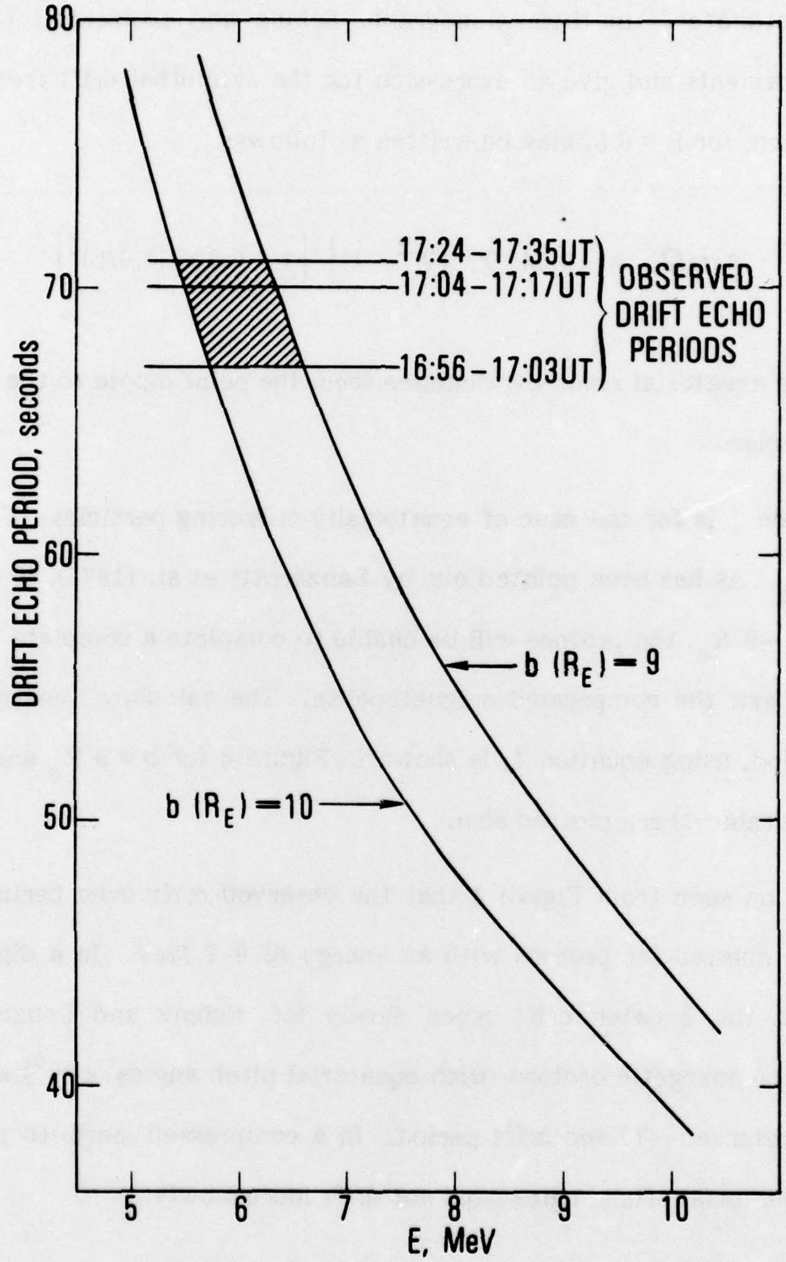


Figure 4. The Calculated Energy Dependence of Drift Echoes, Using Equation 1 in the Text, are Plotted for Values of b, the Equatorial Stand-off Distance from the Point Dip9le to the Magnetopause in the Noon Meridian, of R_E. Also Shown are the Observed Drift Echo Periods During Three Indicated Time Periods.

Drift echoes were not seen clearly in other sc enhancements observed with the Aerospace ATS-1 sensor. The absence of observable drift echoes is not surprising considering the smearing of drift echoes expected from the broad energy channels and omnidirectional response of the Aerospace ATS-1 sensors. However, as pointed out above, the energy spectrum of the sc-accelerated solar protons in this event was very steep, and thus the ATS-1 instrument was counting mainly protons just above 5 MeV. Therefore little smearing of the drift echoes due to energy dispersion results when the steep energy spectrum is convolved with the detector response. Furthermore, the angular distribution of the quasi-trapped solar protons during this event is unknown; the angular distribution may not have been isotropic; the compression (acceleration) event would increase the proton pitch angles. Finally, as noted above, the configuration of the compressed magnetosphere could have been such that the drift period of a proton of a given energy was essentially independent of equatorial pitch angle.

A comparison of the e-folding decay period (Table 1) with the drift period (Table 2) shows that the solar protons were able to make many circuits of the earth on the average before being lost. Clearly the configuration of the outer magnetosphere was unusually conducive to stable trapping of several MeV-protons; the e-folding decay period for the time interval between 63600 sec UT and 64560 sec UT was over twice as long as the longest period observed previously.

The mechanisms(s) for removal of quasitrapped protons from the outer magnetosphere is not known. Paulikas and Blake (1970) pointed out that the gyroradius of a several MeV proton at synchronous altitude is sufficiently large that the usual adiabatic criterion (cf. Singer and Lenchek, 1962),

$$X \equiv \frac{\rho}{|B/\nabla B|} \ll 1 \qquad (2)$$

is not satisfied but that numerical tracing of proton orbits in a model magnetosphere indicated stable trapping. Thus they were led to suggest that pitch angle scattering, in particular interactions with hydromagnetic waves, might be the loss mechanism. Scholer and Morfill (1976) have examined the question of pitch angle and radial diffusion of MeV protons in the outer magnetosphere in detail. They conclude that strong pitch angle scattering in the magnetosphere does not occur during normal quiet times, but strong scattering may occur during geomagnetic storms on those field lines containing ring current plasma.

However there is a difficulty with the loss mechanism being pitch angle scattering into the atmospheric loss cone. Suppose that the quasi trapped protons observed in this sc enhancement event were undergoing strong pitch angle diffusion. Then the minimum lifetime is given (cf. Kennel, 1969; Lyons, 1973; Schulz, 1974) by

$$\tau_m = \frac{\tau_B}{2.2\alpha_0^2} \tag{3}$$

where α_o is the size of the loss cone and τ_B is the proton bounce period. At the synchronous orbit, L=6.6, $\alpha_o \approx 2.5^o$ which yields

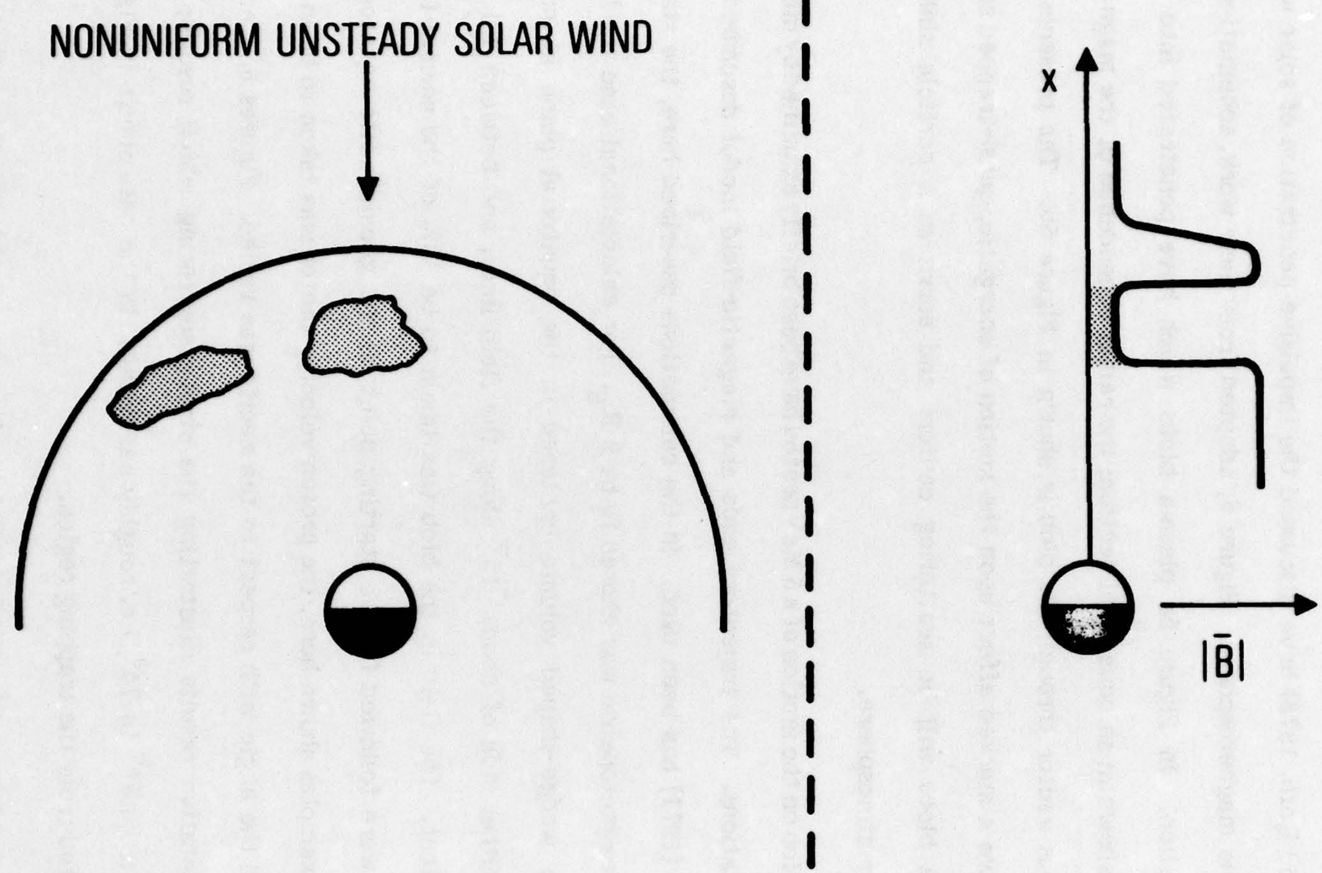
$$\tau_m \sim 240\,\tau_B \tag{4}$$

For a 5 MeV proton, equation (4) gives $\tau_m \sim 16$ minutes. Thus, strong pitch angle diffusion cannot result in proton lifetimes as short as observed at times (~ 5 minutes, Paulikas and Blake, 1970) unless the effective size of the loss cone can be substantially larger than usually assumed. However, Kremser et al. (1977) observed enhanced proton precipitation into the atmosphere following an sc; clearly some of the enhanced proton fluxes do end up in the atmosphere.

Recently Lemaire and colleagues (Lemaire, 1977, 1978; Lemaire and Roth, 1978; Lemaire, Rycroft and Roth, 1978) have discussed the impulsive penetration of solar wind irregularities into the magnetosphere. Figure 5, adapted from their work, schematically illustrates the situation. In Figure 5a plasma blobs which have penetrated into the magnetosphere are shown in an equatorial section; the radial dependence of the magnetic field B along a radius vector through the blob is shown in Figure 5b. The presence of such blobs would have a marked effect upon the motion of energetic, quasi-trapped solar protons; the plasma blobs will be scattering centers and serve as a particle sink in addition to the upper atmosphere.

Effects of a blob on the motion of a 5 MeV proton have been briefly examined by means of trajectory calculations. The trajectory code and magnetic-field model described by Morfill and Quenby (1971) has been used. In the calculations described here, the stand-off distance of the magnetopause was chosen to be 9 R_E. For calculational ease the blob was taken to be a wedge-shaped volume centered in the equatorial plane at noon, extending $\pm 10^{\circ}$ to either side of noon, $\pm 15^{\circ}$ along the field lines, and between 7.0 and 8.5 R_E in radial extent. The field in the blob was taken to be 10% of the normal field intensity. Protons were followed from a starting point on the geomagnetic equator at 1300 LT. For the examples shown here, the proton velocity vector was taken to be in the equatorial plane and the angle with respect to the zenith was varied. Figures 6, 7 and 8 gives some representative results illustrating the strong scattering which results; the zenith angle varies from 88° to 94°, i.e. roughly eastwards. In the case shown in Figure 8 the proton is ejected from the trapping region.

Clearly plasma blobs such as discussed by Lemaire would greatly reduce the lifetime of sudden-commencement enhanced solar protons, and would explain the short



a

b

Figure 5. A Schematic Illustration of Plasma Blob Penetration into the Outer Magnetosphere Adapted from Lemaire and Roth (1978)

observed lifetimes. Multiple blobs, such as depicted in Figure 5, could only increase the loss rate. Of course in general the plasma blobs will be irregular in shape, the internal field non-uniform and non-parallel to the external field. The overall effect, however, would be expected to be much the same as in the idealized case used in generating Figures 6, 7 and 8.

The plasma intrusions also will bring into the magnetosphere the very low energy protons, 2 MeV, which were observed first at synchronous altitude by Lanzerotti (1968, 1970). Low-energy protons which enter through or along a plasma intrusion can drift out into the (quasi) trapping region. It is concluded that these plasma blob effects must occur at times and will help reconcile cutoff and lifetime calculations with experimental observations; field model improvements also help, cf. Pfitzer (1978).

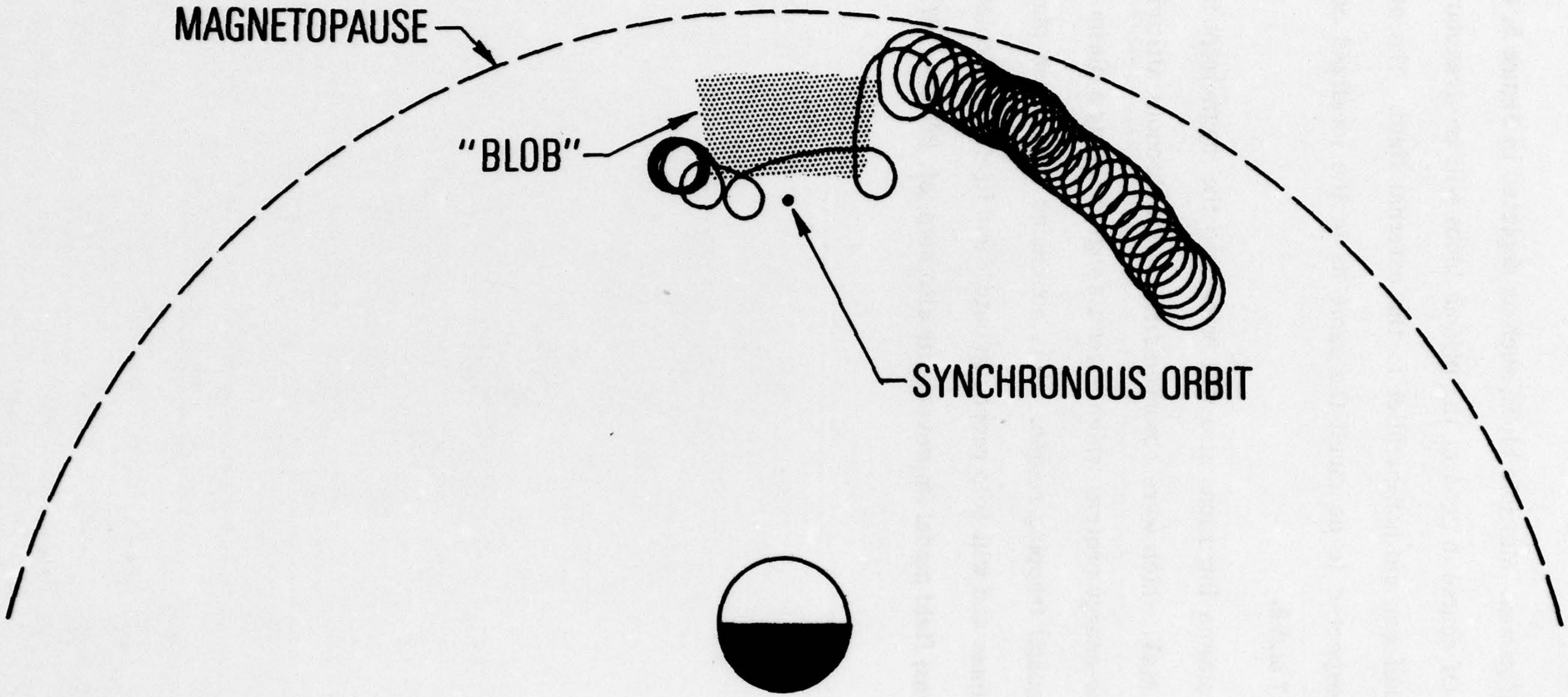


Figure 6. An Equatorial Projection of the Trajectory of a 5 MeV Proton in the Outer Magnetosphere Around the Time of an Encounter with a Plasma Blob. The Plasma Blob is Shown as the Stippled Region. The Proton is Started in the Equatorial Plane at L = 7 at an Angle of 92 deg with Respect to the Zenith (Eastward).

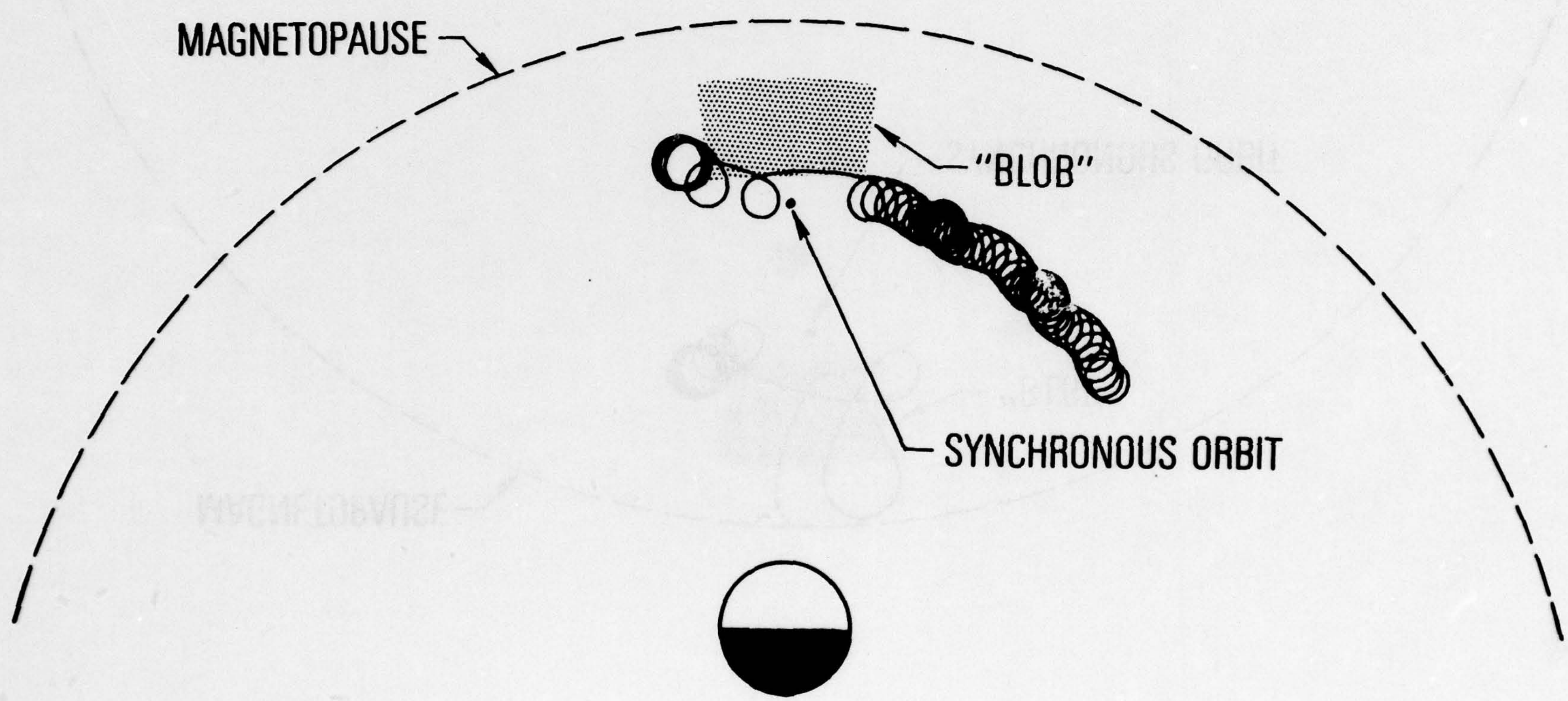


Figure 7. An Equatorial Projection of the Trajectory of a 5 MeV Proton in the Outer Magnetosphere Around the Time of an Encounter with a Plasma Blob. The Plasma Blob is Shown as the Stippled Region. The Proton is Started in the Equatorial Plane at L = 7 at an Angle of 94 deg with Respect to the Zenith (Eastward).

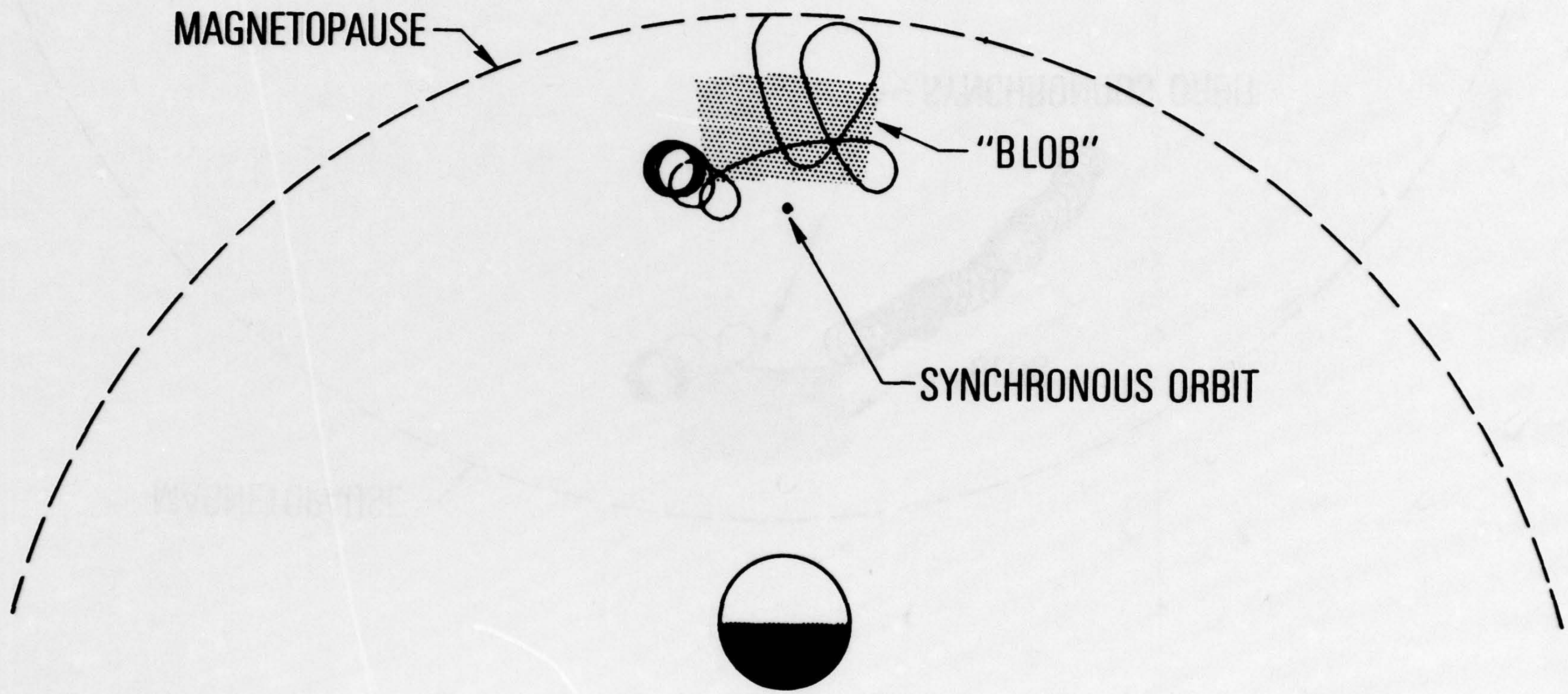


Figure 8. An Equatorial Projection of the Trajectory of a 5 MeV Proton in the Outer Magnetosphere Around the Time of an Encounter with a Plasma Blob. The Plasma Blob is Shown as the Stippled Region. The Proton is Started in the Equatorial Plane at L = 7 at an Angle of 88 deg with Respect to the Zenith (Eastward).

REFERENCES

Blake, J. B., E. F. Martina, and G. A. Paulikas, On the access of solar proton to the synchronous altitude region, J. Geophys. Res., 79, 1345, 1974.

Freden, S. C., and G. A. Paulikas, Trapped proton at low altitude in the south Atlantic anomaly, J. Geophys. Res. 69, 1259, 1964.

Kennel, C. F., Consequences of a magnetospheric plasma, Reviews of Geophys. 1, 379, 1969.

Koopmans, L. H., Spectral Analysis of Time Series, Academic Press, New York, 1974.

Kremser, G., H. Specht, E. Kirsch, K. H. Saeger, and W. Rieder, Energetic solar proton precipitation in the auroral zone associated with storm sudden commencements, Planet. Sp. Sci. 25, 823, 1977.

Lanzerotti, L. J., Penetration of solar protons and alphas to the geomagnetic equator, Phys. Rev. Letts., 21, 929, 1968.

Lanzerotti, L. J., Access of solar particles to synchronous altitude, in Intercorrelated Satellite Observations Related to Solar Events, edited by V. Manno and D. E. Page, p. 205, D. Reidel, Dordrecht, 1970.

Lanzerotti, L. J., C. G. Maclennan, and M. F. Robbins, Proton drift echoes in the magnetosphere, J. Geophys. Res. 76, 259, 1971.

Lemaire, J., Impulsive penetration of filamentary plasma elements into the magnetospheres of the earth and Jupiter, Planet. Sp. Sci., 25, 887, 1977.

Lemaire, J., La penetration du vent solaire dans la magnetosphere, Aeronomica Acta A-188, Belgisch Instituut voor Ruimte Aeronomie, 1978.

Lemaire, J., and M. Roth, Penetration of solar and plasma elements into the magnetosphere, J.A.T.P. 40, 331, 1978.

Lemaire, J., M. J. Rycroft, and M. Roth, Control of impulsive penetration of solar wind irregularities into the magnetosphere by the interplanetary magnetic field direction, Aeronomica Acta A-193, Belgisch Instituut voor Ruimte-Aeronomie, 1978.

Lyons, L. R., Comments on pitch angle diffusion in the radiation belts, J. Geophys. Res. 78, 6793, 1973.

Morfill, G. E., and J. J. Quenby, The entry of solar protons over the solar caps, Planet. Sp. Sci. 19, 1541, 1971.

Paulikas, G. A., J. B. Blake, and S. C. Freden, Inner-zone electrons in 1964 and 1965, J. Geophys. Res. 72, 2011, 1967.

Paulikas, G. A., and J. B. Blake, Effects of sudden commencements on solar protons at the synchronous orbit, J. Geophys. Res. 75, 734, 1970.

Paulikas, G. A., J. B. Blake, and S. S. Imamoto, ATS-6 energetic particle radiation measurement at synchronous altitude, in Proceedings of the IEEE Trans. Aerospace and Electronic Systems, AES-11, 1138, 1975.

Pfitzer, K. A., The effect of magnetic field models on cosmic ray cutoff calculations, in Proceedings of the Chapman Conference on Quantitative Modeling of Magntospheric Processes, in press, 1978.

Scholer, M., and G. E. Morfill, Pitch angle and radial diffusion of mev protons in the outer magnetosphere, J. Geophys. Res. 81, 1737, 1976.

Schulz, M., Particle lifetimes in strong diffusion, Astrophys. Sp. Sci., 31, 37, 1974.

Schulz, M., and L. J. Lanzerotti, Particle diffusion in the radiation belts, p. 153, Springer-Verlag, New York, Heidelberg, Berlin, 1974.

Singer, S. F., and A. M. Lenchek, Geomagnetically trapped radiation, in Elementary Particle and Cosmic Ray Physics, edited by J. G. Wilson and S. A. Wouthnysen, p. 247, North Holland, Amsterdam, 1962.

Thompson, D. J., M. F. Robbins, C. G. Maclennan, and L. J. Lanzerotti, Spectral and windowing techniques in power spectral analysis of geomagnetic data, Phys. Earth and Planet. Interiors, 12, 217, 1976.

Ulrich, T. J., and T. N. Bishop, Maximum entropy spectral analysis and autoregressive decomposition, Rev. Geophys. and Sp. Phys., 13, 183, 1975.

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Chemistry and Physics Laboratory: Atmospheric reactions and atmospheric optics, chemical reactions in polluted atmospheres, chemical reactions of excited species in rocket plumes, chemical thermodynamics, plasma and laser-induced reactions, laser chemistry, propulsion chemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, photosensitive materials and sensors, high precision laser ranging, and the application of physics and chemistry to problems of law enforcement and biomedicine.

Electronics Research Laboratory: Electromagnetic theory, devices, and propagation phenomena, including plasma electromagnetics; quantum electronics, lasers, and electro-optics; communication sciences, applied electronics, semiconducting, superconducting, and crystal device physics, optical and acoustical imaging; atmospheric pollution; millimeter wave and far-infrared technology.

Materials Sciences Laboratory: Development of new materials; metal matrix composites and new forms of carbon; test and evaluation of graphite and ceramics in reentry; spacecraft materials and electronic components in nuclear weapons environment; application of fracture mechanics to stress corrosion and fatigue-induced fractures in structural metals.

Space Sciences Laboratory: Atmospheric and ionospheric physics, radiation from the atmosphere, density and composition of the atmosphere, aurorae and airglow; magnetospheric physics, cosmic rays, generation and propagation of plasma waves in the magnetosphere; solar physics, studies of solar magnetic fields; space astronomy, x-ray astronomy; the effects of nuclear explosions, magnetic storms, and solar activity on the earth's atmosphere, ionosphere, and magnetosphere; the effects of optical, electromagnetic, and particulate radiations in space on space systems.

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